9.—Lake Leschenaultia—an oligotrophic artificial lake in Western Australia

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Abstract

Lake Leschenaultia is a semi-natural freshwater lake established in 1912 on the Darling Scarp 40 km from Perth. In contrast to natural lakes in the south-west of Western Australia, this body of water is deep, low in nutrients, and phytoplankton. The emergent macrophytes are restricted to the lake margin. The area is being developed for public recreation.

Introduction

Wetlands occupy a relatively small part of south-western Australia (Riggert 1966). Among them there is a large proportion of swamps, but there are few freshwater lakes and these are generally very shallow and restricted to the ancient dune systems of the coastal plain (McArthur and Bettenay 1960).

In contrast, Lake Leschenaultia, situated at Chidlow, 40 km east of Perth, and 49 km from the coast, is up to 9 m deep. This spring-fed, freshwater, artificial lake results from a dam built across Cookes Brook and completed in 1912 (Shipway 1948). The lake was used by the Western Australian Government Railways for watering of steam locomotives, and is now being developed for public recreation.

The lake (Fig. 1) is in a laterite basin in the Darling Scarp. It has an area of approximately 40.5 ha (Leggo, pers. comm. 1975), a capacity of 530 million litres and a catchment area of 168.78 ha (Morris, pers. comm. 1975). The bottom of the lake is covered by an organic sediment which becomes deeper and more peaty at the narrower south-western end. A preliminary account of Lake Leschenaultia and its vegetation was published almost 30 years ago (Gentilli 1948; Shipway 1948).

Detailed studies of the chemistry and vegetation of three coastal interdunal lakes are being made by the authors; they are Loch McNess, 50 km north of Perth at Yanchep, Lake Joondalup, 32 km north of Perth at Wanneroo (Congdon and McComb 1976), and Lake Monger in the Perth suburb of Leederville. The present investigation of Lake Leschenaultia was undertaken to provide comparisons with a different lake type, deep and presumably oligotrophic, in the same general climatic region. An artificial lake was chosen because no natural lake of this type is available.

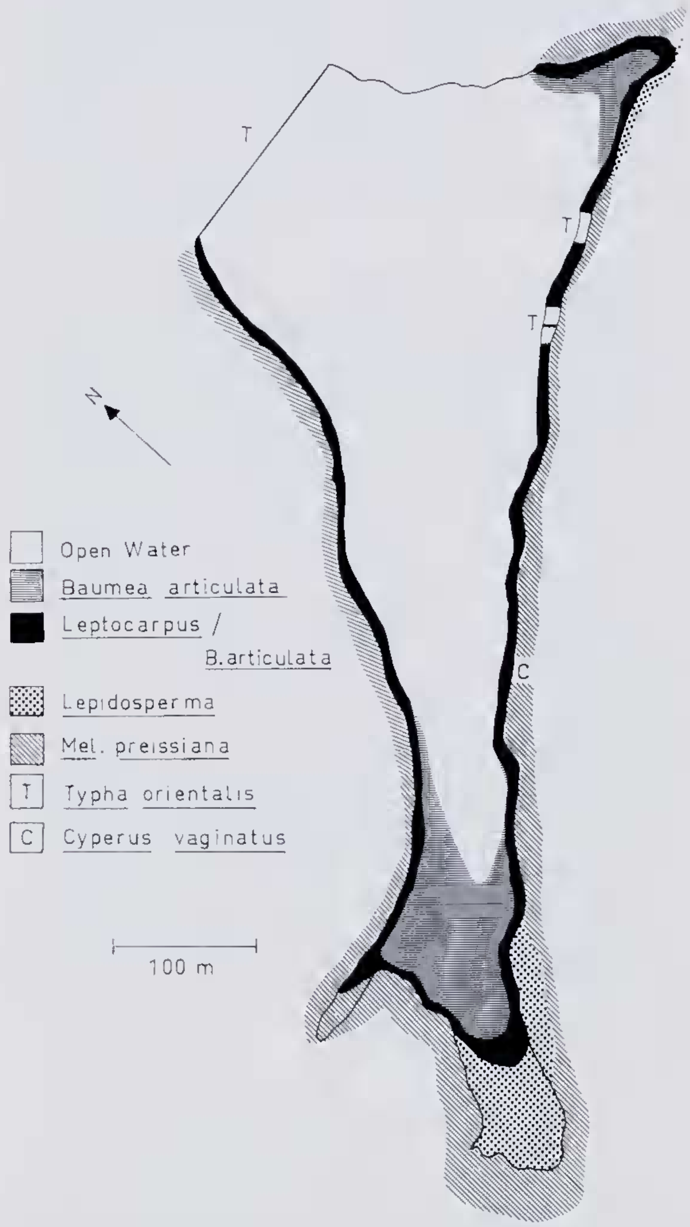

Figure 1.—The plant communities of Lake Leschenaultia.

Benthic and fringing plants

The dominant hydrophyte is *Nitella congesta*, which covers most of the bottom of the lake. In the shallower, narrow part of the lake *Potamogeton tricarinatus* becomes dominant. Other aquatic plants include *Villarsia albiflora* and *Triglochin procera*, which are found at the water's edge in very moist soil and in water up to several centimetres deep.

The fringing vegetation (Fig. 1) appears to have changed little since the descriptions of Gentilli (1948) and Shipway (1948). The dominant fringing macrophytes are *Baumea articulata* (presumably named *Juncus pallidus* in error in

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the earlier papers) and *Leptocarpus aristatus*. *Baumea juncea* occurs sparsely at the north-western shore where the lake narrows and continues to the western end. There is one patch of *Typha orientalis* to the north of the dam wall, and three on the south-eastern shore, of which one is approximately 15 m x 5 m and two are approximately 5 m^2 and 10 m apart. There is one patch of *Cyperus vaginatus* about 10 m^2 on the south-eastern shore. The *Typha* and *Cyperus* appear to have colonized disturbed areas of the south-eastern shore.

Further back from the shoreline the monocotyledons *Lepidosperma angustatum, Restio megalotheca, Restio applanatus* and *Paspalum dilatatum* occur, together with the paperbark *Melaleuca preissiana (M. parviflora)*. *Scirpus nodosus* is found at the south-western end and in patches along the south-eastern shore. *Hakea prostrata* is also found along this south-eastern shore.

The greatest abundance of species is found where there has been an accumulation of silt from the two major inflow streams at the south-western and eastern ends of the lake. *Baumea articulata* extends into water up to one metre deep at the eastern inflow. Other species found at these two sites are *Melaleuca preissiana, Eucalyptus rudis, Viminaria juncea, Acacia cyanophylla*, the sedge *Lepidosperma longitudinale*, and the insectivorous herbs *Drosera heterophylla* and *Polypompholyx* spp. The sedges and larger dicotyledons stabilize the silt which is discharged in these areas from the inflowing streams. Voucher specimens of the hydrophytes have been lodged in the Herbarium of the Department of Botany, University of Western Australia.

The surrounding forest is a *Eucalyptus marginata—Eucalyptus calophylla* association, with *Eucalyptus wandoo* present on the south-eastern and eastern sides of the lake. A road around the lake comes to within 10 m of the waterline on the north-western side, and 20-30 m on the south-eastern side. The vegetation appears more disturbed on the north-western side of the lake, where there is reduction in ground cover, marked by the presence of gravel deserts (Gentilli 1948) and an increase in exotic species such as the thistle *Sonchus asper*.

Biological aspects of the open water

Phytoplankton

Water was collected from just below the surface at 4 sites on the lake, bulked, and the plankton in a one litre sub-sample concentrated by centrifuging at 2000 xg for 15 minutes. The supernatant was removed by suction and the residue resuspended and counted, using a counting chamber, (Gelman Hawksley Ltd., England) with a grid size of 0.0025 mm^2, and a depth of 0.1 mm. Eight replicates of 25 fields were scanned, i.e. 200 fields of view.

Plankton levels were extremely low and no measurable estimates per unit volume could be given, even though the method gave high levels for other lakes (Table 1). Species seen at very low frequency during the study, though not necessarily within the grid, were *Lyngbya limnetica* Lemm., *Navicula* sp., *Spirogyra* sp., and *Pediastrum duplex* Meyen.

Table 1

Total counts and chlorophyll 'a' levels for Lake Leschenaultia and three coastal lakes in May 1975

Lake	Total Number/litre	Chlorophyll 'a' (mg/m^3)
Leschenaultia	$<6 \times 10^4$	<0.10
Monger	540×10^4	1.58
Joondalup	2800×10^4	3.94
McNess	55×10^4	0.44

As an estimate of biomass along with these direct counts, chlorophyll 'a' per litre of lake water was determined, using a modification of the trichromatic technique of Richards with Thompson (1952). Again, the pigment extract gave absorbancy readings which were too low to be used for calculating pigment amounts. For comparison, the chlorophyll 'a' levels of three coastal lakes are included in Table 1.

Lake bathymetry and physico-chemical aspects

Depth soundings were made along two transects at 50 m intervals, measured with the buoy and float method described by Welch (1948). The transects were taken across the length and breadth of the lake. The results were transposed onto Figure 2, which is derived from an aerial photograph supplied by the Department of Lands and Surveys.

A comparative measure of light transparency was obtained with a 20 cm-diameter Secchi disk. pH was measured in the field using a portable meter (E 488, Metrohm Ltd., Herisau, Switzerland). Specific conductivity was measured on return to the laboratory with a conductivity meter (E 382, Metrohm Ltd., Herisau, Switzerland) and converted to a standard temperature of 18°C using the formula of Bayly and Williams (1973).

Table 2

Some physico-chemical characteristics of Lake Leschenaultia compared with Loch McNess, Lake Monger and Lake Joondalup for May 1975

	Leschenaultia	McNess	Monger	Joondalup
Maximum depth (m)	9.0	1.5	1.9	1.4
Secchi transparency (m)	4.2	100%	100%	0.8
pH	7.6	7.8	8.7	9.2
K_{18} ($mS.cm^{-1}$)	1.13	0.45	0.85	1.76

Some basic physico-chemical parameters of the lake are presented in Table 2 and compared with the other lakes under study. Lake Leschenaultia has by far the greatest depth. It also has a high Secchi transparency for May 1975, and this transparency correlates with a low phytoplankton standing crop.

All the lakes are alkaline but Leschenaultia has the lowest pH. Monger, Joondalup and Loch McNess lie in the Spearwood dune system of calcareous sands overlying aeolianite (McArthur and Bettenay 1960), and this probably accounts for their higher pH values. Loch McNess lies in

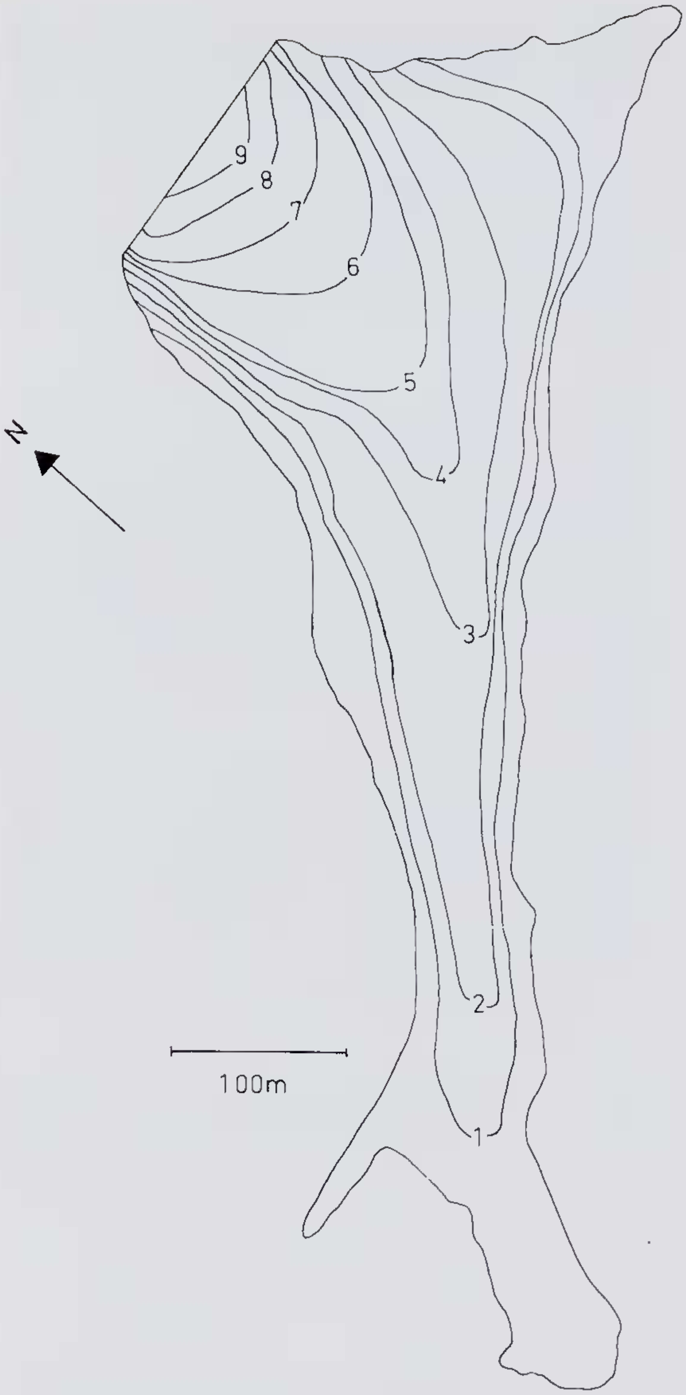

Figure 2.—Depth contours for Lake Leschenaultia. One metre intervals, recorded May, 1975.

close proximity to extensive fens (McComb and McComb 1967) which may contribute humic acids which would modify the pH.

The specific conductance of Lake Leschenaultia is relatively high compared with the other lakes, only being exceeded by Lake Joondalup. This is a reflection of the high ion levels (see below).

Dissolved oxygen

Oxygen was measured with an oxygen meter (YSI Model 51B, Yellow Springs Instrument Co., Yellow Springs, Ohio) calibrated by an air-saturation technique. This meter allowed compensation for temperature, air pressure and chloride concentration in the water. Readings were taken at different depths in order to check for stratification. On one occasion oxygen levels at the same site were compared for surface water collected at midday, and at depth using the azide modification of the Winkler method (Anon. 1971) A Hales water sampler, described by Welch (1948), was used to collect the bottom sample. All samples were fixed in the field.

Results are given in Table 3. No stratification was observed for oxygen over depth. However, an oxygen profile taken during September at the same site as that in June, showed a significant difference between top and bottom oxygen levels. It would appear that an oxygen gradient may persist at certain times of the year.

Table 3

Oxygen levels in Lake Leschenaultia (mg/litre)

	June			September	
Depth (m)	°C	Dissolved oxygen Meter	Dissolved oxygen Winkler	°C	Dissolved oxygen Meter
Surface	14.2	8.8	8.7	14.6	10.5
1	14.0	8.8	....	14.2	9.4
2	13.8	8.8	....	14.2	8.4
3	13.6	8.8	....	13.4	6.6
4	13.5	8.8	....	13.0	5.6
5	13.4	8.8	....	13.0	5.2
6	13.4	8.8	8.7		

Cation-anion balance

The ionic concentrations of most shallow lakes of the Swan Coastal Plain change seasonally with lake volume, which is in turn related to rainfall (Congdon and McComb 1976). Loch McNess may be an exception, in that the level is relatively constant seasonally, as the lake basin overflows (McComb and McComb 1967). Short term comparative studies between lakes must therefore take this effect into account.

Figure 3 gives the monthly rainfalls for the areas in which the four lakes lie. There is a very close relationship between the rainfalls of Perth (Lake Monger), Wanneroo (Lake Joondalup) and Chidlow (Lake Leschenaultia). The figures for Yanchep (Loch McNess) are not as closely correlated, but the same trends are apparent. Consequently, the ion levels in the lakes might well be meaningfully compared for a particular month.

The metallic cations were determined by atomic absorption spectroscopy. Chloride was determined potenticmetrically using an automatic chloride titrator. Bicarbonate was determined by the double indicator method and sulphate by the turbidimetric method (Anon. 1971).

The ion levels are comparable to those found by Congdon and McComb (1976) for Lake Joondalup in May 1973. These levels are high compared with freshwater lakes throughout the world, although Australia possesses many athalassic saline lakes (Bayly and Williams 1973).

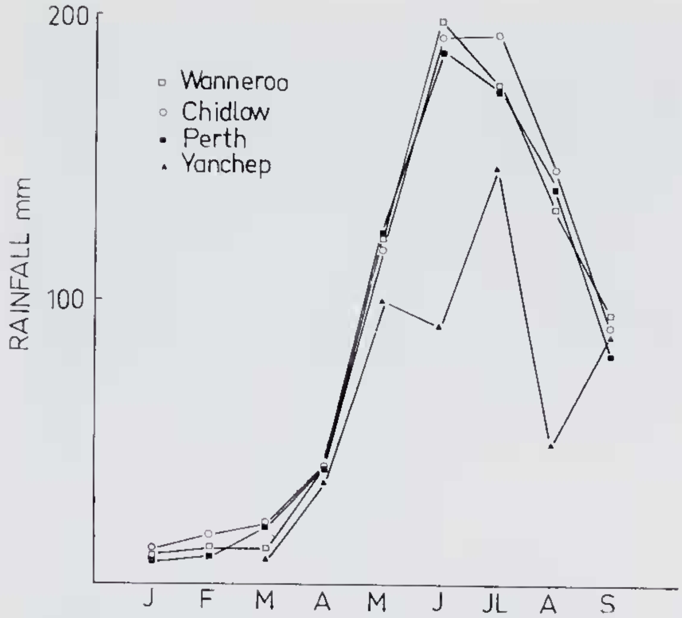

Figure 3.—Monthly rainfall figures for lake regions. (Yanchep figures courtesy of National Park's Board; others courtesy of Bureau of Meteorology.)

The order of dominance of the cations is Na>Mg>Ca>K and that of the anions is $Cl>HCO_3>SO_4$. This order is the same as in seawater but the percentage equivalence values are not closely correlated with those of seawater, being relatively low in Na and K, and relatively high in Mg and Ca (Table 4).

Lateritic profiles in the Darling Range show soluble salts stored in the pallid zone and these are released following clearing of native hardwood forests (Dimmock *et al.* 1974). These salts are believed to have originated largely from long term atmospheric accessions in rainfall (Peck and Hurle 1973). This may well be the source of the major ions in Lake Leschenaultia. The derivation of ions from rainwater of oceanic origin has been postulated for coastal dune lakes of New South Wales and Queensland (Bayly 1964). Blue Lake in South Australia (Bayly and Williams 1964) and Lake Joondalup in Western Australia (Congdon and McComb 1976).

At the time of sampling there was no significant difference between the ionic composition of the surface water and water from 6.5 m, except for increased sulphate at depth. This is in accord with Mortimer's (1941-1942) results for aerated water over mud.

Silica

Reactive silicate was determined by the reduced β-silico-molybdate method (Major *et al.* 1972). There was little variation in silica level with depth (Table 5). Comparison with the range of silica levels for other freshwater lakes (Hutchinson 1957), indicates that values found here are relatively low. In considering a temperate, deep water lake, Mortimer (1941-1942) found silicate levels, under aerobic conditions, ranged from a few to 20 000-30 000 μg/litre in Lake Windermere.

Presence of silica in lake water is generally correlated with diatom populations, which play a significant role in reducing silicate levels through direct utilization. Though it would be unwise to generalise from the May data to other seasons, it would seem reasonable to suggest that the levels found in Lake Leschenaultia are due to drainage patterns providing silica from silicate mineral decomposition, rather than from diatoms in the water, which were at very low numbers at the time of sampling.

Phosphorus

Water collected for total phosphorus determinations was frozen as soon as possible after collection. The samples collected for inorganic

Table 4

Major cations and anions found in Lake Leschenaultia in May 1975, with some data for seawater for comparison

Depth	Units	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}
surface	mg/litre	194	2.8	11.7	38	380	30.5	4.5
	%meq/litre	69	0.5	5	25.5	95	4	1
6.5m	mg/litre	190	2.8	11.6	39	380	30.5	12.0
	%meq/litre	68	0.5	5	26.5	93.5	4.5	2
seawater[1]	g/litre	10.8	0.4	0.4	1.3	19.4	0.1	2.7
	%eq/litre	77.1	1.6	3.3	18	90.2	....	9.8

[1]Figures for seawater taken from Parker (1972).

Table 5

Nutrient levels in Lake Leschenaultia and three other lakes on the coastal plain for May 1975

Lake	Depth	Nutrient (μg/litre)						
		Si	Tot P	PO_4–P	Org–P	NH_3–N	NO_3–N	NO_2–N
Leschenaultia	surface	274	10	8	2	11.4	61	13
Leschenaultia	6m	280	20	8	12	12.5	20	20
Monger	surface	...	21	<1	21	33.6	594	16
Joondalup	surface	....	38	2	36	14.8	813	33
McNess	surface	....	7	<1	7	4.1	813	12

(ortho) phosphate determination were placed in polyethylene bottles previously soaked in a KI/iodine mixture and determined by the single solution method (Major *et al.* 1972). Total phosphorus was determined by the same method after perchloric acid digestion. Surface and depth readings obtained for Lake Leschenaultia during May 1975 are given in Table 5 along with levels found in three other lakes.

Levels of phosphorus in Lake Leschenaultia were relatively low. Hutchinson (1957), in a review of a number of geographically-distinct lakes found in humid, temperate regions, noted uniform low concentration of total P in surface waters. Though within 80 km of Lake Leschenaultia the three coastal lakes, used for comparison, gave contrasting phosphorus levels. Lake Monger, a well established, shallow alkaline lake, sometimes subject to intense algal blooms and considered to be fairly eutrophic, gave total phosphorus readings during May which were similar to those for bottom water in Lake Leschenaultia. However, levels of phosphorus during this period were declining in Lake Monger and it is noteworthy that levels of 60-70 μg/litre have been reported during this month in this lake in earlier years (Harris 1969). A similar trend was found for total phosphorus in Lake Joondalup, considered to be mildly eutrophic (Congdon and McComb 1976). Closer agreement was found between the values for Lake Leschenaultia and Loch McNess, the latter being the least disturbed and least productive of the coastal lakes.

Inorganic phosphorus comprised a significant part of total phosphorus in Leschenaultia, being 80% of total surface water phosphorus. Much of the phosphorus utilised by phytoplankton in lakewater is in this fraction. From the large amounts of PO_4-P relative to total P, it is suggested that low phytoplankton numbers, and thus little utilisation of the phosphate fraction, may be responsible. This may be further borne out from comparison with the coastal lakes, where reduced orthophosphate levels occur where algal population numbers are significant.

Levels of organic phosphorus were higher at depth, though the orthophosphate fraction remained constant. Phytoplankton levels were minimal during May, and it can only be assumed that organic material was present at depth, derived from benthic or fringing plants.

Nitrogen

Inorganic nitrogen was determined by individually testing for ammonia, nitrate and nitrite. Ammonia was detected by the cyanurate method (Dal Pont *et al.* 1974). Nitrate was detected by an ultra-violet method which takes into account interference by organic nitrogen (Anon. 1971). The nitrite concentration was tested by a diazotisation method which involved coupling diazotised sulfanilic acid with naphthylamine hydrochloride (Anon. 1971).

Ammonia was found in similar concentrations at both depths (Table 5), but differences occurred in concentration of nitrite and nitrate. The nitrate was more concentrated at the surface. (The lower value of 20 μg/litre may not be entirely accurate as the ultra-violet technique has a recommended lower detection limit of 40 μg/litre (Anon. 1971).) The level reported here is lower than that given by Shipway (1948) (10 mg NO_3-N/litre). As no information on the technique used to measure the early sample is available it would be unwise to draw conclusions from the comparison, as many nitrate methods have been found to be unreliable (eg. Vollenweider 1968). Nitrite was higher in the 6 m sample but the relatively minor role this element plays in the environment (Malhotra and Zanoni 1970) reduces the significance of this change.

Using inorganic nitrogen values for Lakes Joondalup, Monger and McNess (Table 5) it is possible to gain an indication of the relative trophic level of Lake Leschenaultia. The nitrite concentration places Leschenaultia between McNess and Joondalup and very similar to Monger, but as this compound is so transient in the environment, little emphasis should be placed on this comparison. The nitrate found is considerably lower than levels found in the other three lakes. As the level of nitrate in oligotrophic lakes rarely exceeds 1 mg/litre NO_3-N (Bayly and Williams 1973), it seems reasonable to classify Lake Leschenaultia as oligotrophic, at least on this one occasion, on this basis. An attempt was made to read nutrient levels, as total P and inorganic nitrogen, onto tables classifying lakes into their trophic status. Using the table of Sakamoto (1966) (cited Vollenweider 1968), Lake Leschenaultia can again be classified as oligotrophic. Thus, from a consideration of nutrient levels (as N, P and Si), phytoplankton populations and physical state of the water using information for other lakes in the area, and information from the literature as a guideline, it is suggested Lake Leschenaultia be designated oligotrophic.

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